OPEN VERTICAL VOLCANIC CONDUITS: A PRELIMINARY INVESTIGATION OF AN UNUSUAL VOLCANIC CAVE FORM WITH EXAMPLES FROM NEWBERRY VOLCANO AND THE CENTRAL HIGH CASCADES OF OREGON

Craig E. Skinner
University of Oregon

1.0 INTRODUCTION

A wide variety of cavernous structures is found in rocks of volcanic origin. Of these, the best known and most thoroughly investigated has been the lava tube cave. Substantial studies of investigators such as Ollier and Brown (1965), Hatheway (1971), Greeley (1971), Halliday (1976) and Wood (1978) were carried out on lava tube and collapse depression systems in the 1960s and 1970s, stimulated in part by interest in analogous structures found on the Moon and later, on Mars.

There are, however, a number of minor and largely neglected forms of lava caves that are known to exist in extrusive volcanic rocks. One of the most unusual and interesting of these, the *open vertical conduit,* is the subject of this paper.

The open vertical conduit (hereafter referred to as the OVC) is an unusual structure found in recent volcanic rocks. The OVC is a nearly round or oval-shaped vertical tube ranging in depth from a few feet to at least 165 feet (50 m), though I will qualify this figure later. The diameter of the vertical tube, or conduit, varies from less than a foot to about 25 feet (8 m), though in the open conduits examined in this paper, the usual diameter was less than 10 feet (3 m). The interior lining of the OVC typically consists of remelted lavas that form a relatively smooth lining several cm in thickness that may be decorated with short lavacicles. The remelted lining of the conduit betrays the high temperature environment that once existed at the OVC, a vent for lavas and hot gases. In profile, many OVCs are bell-shaped (see Figure 2) when found in association with spatter cones and ramparts, though when found with hornitos, the conduit may open directly into a lava tube (also see Figure 2).

It also appears that an OVC can be found alone or that it may co-exist with other lava cave varieties such as spatter cone chambers, spatter-roofed fissure vents and lava tubes. The term *open vertical conduit cave* is probably best applied when the OVC is the dominant cave-forming feature and is not merely a minor adjunct structure found with another lava cave. When found in combination with other cave types, the combined depth of the conduit and the associated cave may extend beyond the length of the OVC alone. This was clearly the case at one of the caves examined, the Upper McKenzie Pits, and, no doubt, is true of other examples.

Specific landforms are found in association with all OVCs. Assorted sizes of spatter cones, spatter ramparts and hornitos invariably surround the OVC, again providing evidence of its function as a vent. OVCs are found in both pahoehoe and aa lavas, though most of the examples discussed in this paper occur in aa lavas.

OVCs are found at both primary and secondary (rootless) vents where they are representative of the final stages of volcanic activity.

I also want to clarify what an OVC *is not*, as it is possible to confuse them with at least three other, similar volcanic features of considerably different origin. The OVC is not a collapse feature such as a ceiling "skylight" entrance into a lava cave; the two can be easily distinguished by the lack of a remelted lining in the collapse feature.

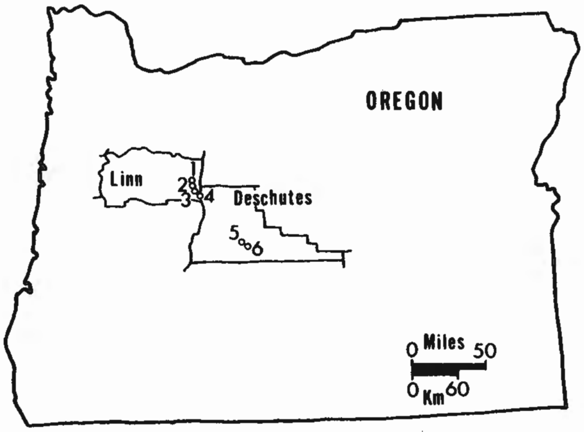
More closely resembling the OVC are some vertical lava tree molds. It is not surprising that these upright molds could be confused as a vent structure, for they have a smooth interior lining combined with a round cross-section. The term *mortar* once had been applied to lava tree molds in the belief that they were small vents (Wentworth and MacDonald, 1953:55). OVCs can easily be distinguished from tree molds by the lack of accumulated spatter around the mold entrance, impressions of bark on the wall of the mold and the presence of nearby horizontal tree molds. [Editor's note: lava accretions are present around some tree casts or molds in the Cave Basalt, Mount St. Helens, Washington, and presumably elsewhere.]

Also possibly confused with an OVC is a structure created by the drainback of lava into a vent as the level of magma drops below the vent. This phenomenon is mentioned by Wood (1976a:130) and is documented by Swanson *et al.* (1979:31,32).

When found in association with spatter cones, most OVCs connect with a circular chamber, the floor of which extends below the outside ground level. A similar, beehive-shaped room can sometimes be found inside hornitos, though no OVC is also present, and the "beehive" is entered through collapsed or ruptured sections of the top or sides. These peculiar caves, not to be confused with OVC caves in spatter cones or hornitos, have been reported in New Mexico (Nichols, 1944:1062), in Idaho (Russell, 1902:101), at Jordan Craters in southeastern Oregon (Russell, 1903:52; Kittleman, 1962:107-108; Millhollen, 1965:22) and adjacent to the Devils Garden lava field in Central Oregon (Peterson and Groh, 1965:26). Several unreported examples are also found near Katati Butte not far south of Oregon's Newberry Volcano.

2.0 RESEARCH CONSIDERATIONS

The general aim of this paper is to describe the morphology, geographic distribution, possible modes of genesis, associated volcanic landforms and age and composition of the open vertical conduit (OVC). Another problem that I have been trying to clarify is whether the OVC qualifies as a specific cave



1 SANTIAM PIT
2 UPPER McKENZIE PITS
3 SAND MOUNTAIN CHIMNEYS
4 LITTLE BELKNAP PIT
5 SMITH'S PIT
6 NORTHWEST RIFT ZONE PITS

Figure 1. *The location of the six open vertical conduits or groups of conduits examined in this paper.*

type or whether it is merely found in association with other types. My answer, at this point, is that it may be either. Answers to these questions were gathered through the comparative investigation of several OVCs that are found in the central High Cascades of Oregon and along the northwest flanks of Newberry Volcano in central Oregon (Figure 1).

My investigation was largely qualitative. Once the conduits were located, they were mapped (if no prior map existed) and carefully examined. Analogies from observations of active volcanic activity were then sought in the literature in an attempt to reconstruct the eruptive history of each Oregon OVC. In addition, the literature was examined for other examples of open conduits. This search, while only moderately successful, led to the identification of several other definite cases, as well as several rather tentative ones, all of which are briefly mentioned in part 5 of this paper.

Regional geology, radiocarbon age determinations and the composition of lavas that were associated with the OVCs were available from several sources and all added substantially to the body of this preliminary investigation. X-ray fluorescence spectrometry supplemented by Atomic absorption analysis (for Na) was used to obtain some of the comparative data that appear in Table 2. This was carried out in the facilities of the X-ray fluorescence laboratory at the University of Oregon.

3.0 TERMINOLOGY

A number of terms are used quite specifically in this paper and to avoid confusion, I will define them at this point. All definitions are adapted from Wentworth and MacDonald (1953).

Primary Vent: An eruptive fissure or vent that is directly associated with the conduits that have brought magma from an underground reservoir to the surface.

Secondary (Rootless) Vent: A vent that is not directly associated with a primary vent. Several types or rootless vents are distinguished by Wentworth and MacDonald (1953:26-27) but the ones relevant to this discussion are those vents at hornitos that are fed (from a primary vent) through lava tubes.

Spatter Cone: These are small features (usually less than 50 feet in height), created at primary vents as molten and plastic clots of spatter adhere to form a cone of agglutinate.

Spatter Rampart: Similar to spatter cones, the spatter ramparts (sometimes called spatter ridges) are walls of welded spatter that are built by fountaining along a primary fissure vent. The accumulation of spatter creates a rampart ranging in height from a few inches to over 20 feet (6 m).

Hornito: These are mounds of spatter--usually small--that are built over rootless vents. Closely resembling spatter cones, hornitos are often confused with spatter cones, and spatter cones with hornitos.

The term open vertical conduit is adopted in this paper in order to describe the open vertical volcanic vents investigated. Other authors, however, have applied similar names to this variety of lava cave. Taylor (1965:126; 1967:9,12), when describing several OVCs in the High Cascades of Oregon, called them vertical conduits. I have simply added *open* to this term to eliminate any confusion between open conduits and filled conduits sometimes exposed in modified or eroded volcanoes. Nieland (1970:233), refers to some of the open conduits described by Taylor as "spatter cone pits." Russell (1902:81, 100-101; 1903:40), describing some examples in Idaho, labels them "chimneys" and Ollier (1964:68)

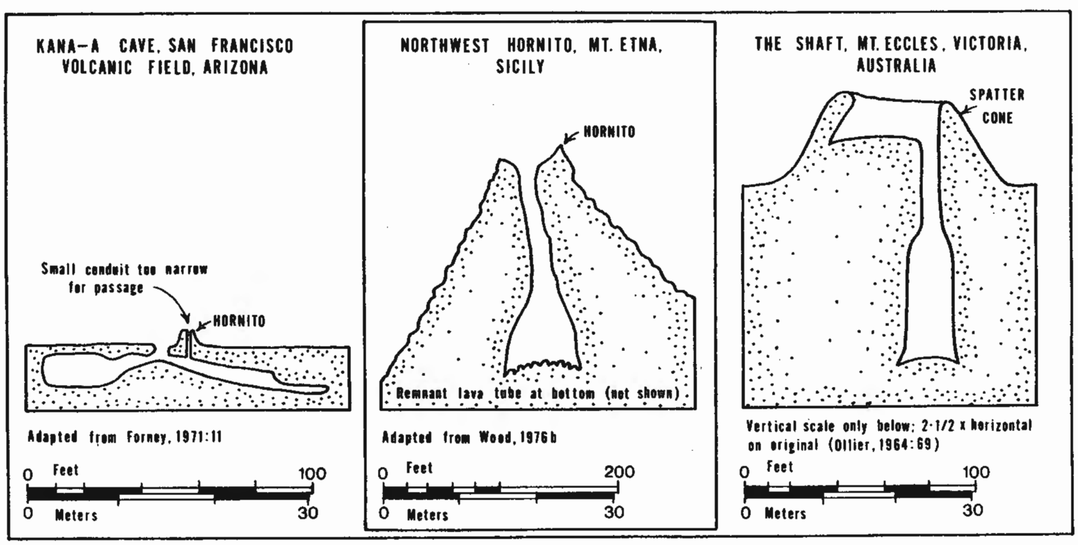


Figure 2. *Three confirmed examples of open vertical conduits that are reported by other authors.*

simply calls them open vents. [Editor's note: Russell's terminology is reflected in such names at Lava Beds National Monument, California, as Fleener Chimneys.]

4.0 PREVIOUS RESEARCH

Detailed descriptions of OVCs appear to be non-existent and only a few general references to this volcanic feature are found in the literature.

Wentworth and MacDonald (1953:53) state that hornitos commonly have an open pipe at the center, though they provide no details.

Wood (1976a:131) makes only a passing note of cavities beneath spatter cones, some of which are associated with OVCs.

MacDonald (1972:189) offers a brief description of OVCs found with spatter cones when he writes: "Welded spatter can stand in a bank that is essentially vertical . . . and the crater wall may be steep and irregular; and occasionally a pipe-like or fissure-like conduit may remain open to a depth of several tens of feet below the bottom of the crater."

In his early geologic study of the Snake River Plains of Idaho, Russell (1902:100-101) makes the earliest mention of OVCs: "There is still another variety of lava caverns due to the blowing out by escaping steam of still liquid or highly plastic lava through openings in a solid crust. The chimney-like openings in the parasitic cones . . . are examples of 'vertical caverns' . . . the cones . . . contain far more material than the vertical openings within them could have furnished. This is apparent when it is remembered that the vertical shafts are principally in the built up portions of the 'chimneys,' and hence the material must have been supplied in large part by the horizontal galleries to which the vertical shafts lead."

Other mentions of OVCs in the literature tend to be brief and purely descriptive and are considered in the next section of this paper. It was this noticeable void in information on OVCs that eventually impelled me to complete the investigation reported in this paper.

5.0 GEOGRAPHIC DESCRIPTION

Because OVCs are not a well-documented volcanic feature and the few examples are not described in detail, it was often difficult to ascertain whether a volcanic cave was, in actuality, an OVC or contained an OVC, or whether it was a structure that only resembled an OVC. Several probable examples, however, were located in a relatively extensive literature search, exclusive of the Oregon OVCs that are described below:

1. The Shaft, a spatter cone and OVC found on the slopes of Mt. Eccles in Australia (Ollier, 1964:68-69; see Figure 2).
2. The Due Pizza northwest hornito and OVC, a 165-foot (50 m) shaft on the slopes of Mt. Etna in Sicily. Located nearby and also known as Due Pizza is another hornito and OVC (Wood, 1976b:24-25; see Figure 2).
3. Kana-A Cave, a small hornito and lava tube in the San Francisco Volcanic Field of Arizona (Forney, 1971:10-11; see Figure 2).
4. The Ice Wells, an OVC or OVCs found in the Craters of the Moon National Monument of Idaho (Russell, 1902:101-102 and 1903:46; Stearns, 1928:19).
5. Spatter Cone Cave, Diamond Craters, Oregon, a small cone and OVC leading to a short lava tube (Benedict *et al.*, 1979).
6. The Bandera Crater Lava Tube, Bandera Lava Field, New Mexico; a hornito, possibly one of several, and OVC leading to a lava tube (Hatheway, 1971:216; Hatheway and Herring, 1970:325).

Several other caves were also located that might contain OVCs or be considered as OVC caves but whose description was not adequate to verify that fact. They were: the Algar de Funil on the island of Terceira in the Azores (Halliday, 1980:120); the Algar de Carvao, also located on the island of Terceira (Halliday and Others, 1978:28-29); the Caldeira of Graciosa chimney on the island of Graciosa, Azores (Pickering, 1908:347-49; Halliday and Others, 1978:30-31; and unknown open conduits and hornitos in the Hawaiian Islands (Wentworth and MacDonald 1953:52).

6.0 EXAMPLES OF OPEN VERTICAL CONDUITS FROM THE NORTHWEST RIFT ZONE OF NEWBERRY VOLCANO

The Northwest Rift Zone of Newberry Volcano is a narrow, 20-mile (32 km)-long belt of *en echelon* faulting and fissure eruptions on the northwest flank of Newberry Volcano, a massive composite volcano southeast of Bend. The rift zone stretches from the shores of East Lake in Newberry Caldera to Lava Butte near Bend (Figure 3). This zone of post-Mazama fissure activity has been dated at about 6,000 radiocarbon years in age. Activity along the rift zone was first described as a whole by Nichols and Stearns (1938) and anonymously (1939) and later, in more detail, by Peterson and Groh (1965:8-9; 1969).

A combination of quiet fissure eruptions and lava fountaining produced a wide variety of landforms along the fissure vents. These include several basaltic to basaltic-andesite aa flows, spatter cones, spatter ramparts, scores of lava tree molds and several OVCs.

These conduits, ranging in depth from only a few feet to over 30 feet (10 m) are found in two areas, one near the Lava Cast Forest and the others between the Lava Cascade and North Summit Flows.

6.1 UPPER NORTHWEST RIFT ZONE OPEN VERTICAL CONDUITS

In contrast to the several flows that originated from fissure vents along the middle and lower portions of the rift zone, the upper section is characterized by only small effusions of lava. Instead, most activity was restricted to a single small flow and several narrow zones of coalescent craters aligned along the eruptive fissure. Figure 4 illustrates one of these chains. In at least two locations along an area of the fissure known as "The Crack," OVCs have developed, rather than the simple spatter pits in Figure 4. One of the OVCs, though only penetrable

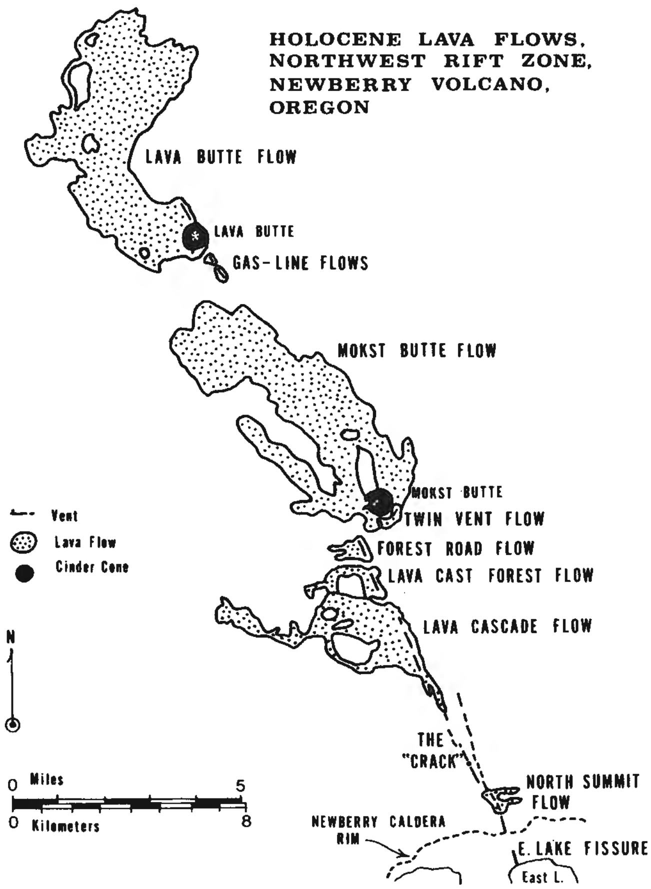


Figure 3. A post-Mazama (younger than about 7,000 radiocarbon years B.P.) flow of basalt and basaltic andesite along the Northwest Rift Zone of Newberry Volcano (base map is adapted from Peterson and Groh, 1965:8).

three feet (1 m) before a plug is encountered, clearly shows the typical circular vertical and lined structure of the OVC.

Not far from this shallow conduit is the best example of an OVC along the upper section of the rift zone. This as-yet-unentered conduit is 8 feet (2.5 m) in diameter. As yet, it is unentered, but it can be seen to plunge at least 30 feet (10 m) and evinces the typical structure of the OVCs examined. The conduit lies directly over the main fissure vent and represents a localized focus of activity along a short segment of coalescent spatter pits.

6.2 SMITHS PIT

Lying nearly parallel to the main vents of the Lava Cast Forest Flow is an alignment of two spatter cones and two spatter-rimmed cinder cones. Found a half-mile (1 km) east of the Lava Cast Forests vents and possibly contemporaneous with the activity there, this group of cones is the site of another example of an OVC, Smith's Pit.

This pit (Figure 5), first described briefly by Larson (1973), consists of a 1.5 by 3 foot (.5 by 1 m) oval conduit entrance that quickly bells out into a small chamber. The floor of the chamber is about 10 feet (3 m) beneath the outside ground level. It lies 23 feet (7 m) below the entrance to the OVC. Seen on the chamber walls are numerous horizontal bench marks, remnants of different levels of magma stands inside the spatter cone. Its interior remelted lining is completely intact. Clearly this was a chimney-like vent during the final stages of activity. The structure is quite typical.

7.0 EXAMPLES OF OPEN VERTICAL CONDUITS FROM THE CENTRAL HIGH CASCADES

Situated between Three-Fingered Jack and the South Sister in Oregon's High Cascades is one of the largest displays of post-glacial volcanic activity in the Western United States. Here are over 85 square miles (200 km^2) of lava flows and dozens of cinder cones and vents. They prompted Howel Williams (1944:37) to write: ". . . for wealth of recent lavas . . . no part of this range surpasses the area embracing the Sisters and McKenzie Pass."

The Holocene lavas in this region are associated with an unusual number of excellent examples of OVCs. At vents on Little Belknap Crater and at several locations along the Sand Mountain Alignment (a linear chain of cones and vents) are a diverse collection of open conduits (Figure 6).

7.1 LITTLE BELKNAP CRATER CAVE SYSTEM

A spatter-roofed feeder conduit near the summit of Little Belknap Crater supplied a short cave system now composed of several small lava tubes. The most unusual system of this OVC is at the bottom of the conduit. Here is found another lava tube system that apparently acted as a drain, leaving open the conduit that led to the upper system (Figure 7). The presence of a two-level lava tube system and interconnecting OVC at a primary vent appears to be quite unusual.

This small but complex cave appeared in the literature as early as 1925 (Hodge, 1925:50-51) and several times since

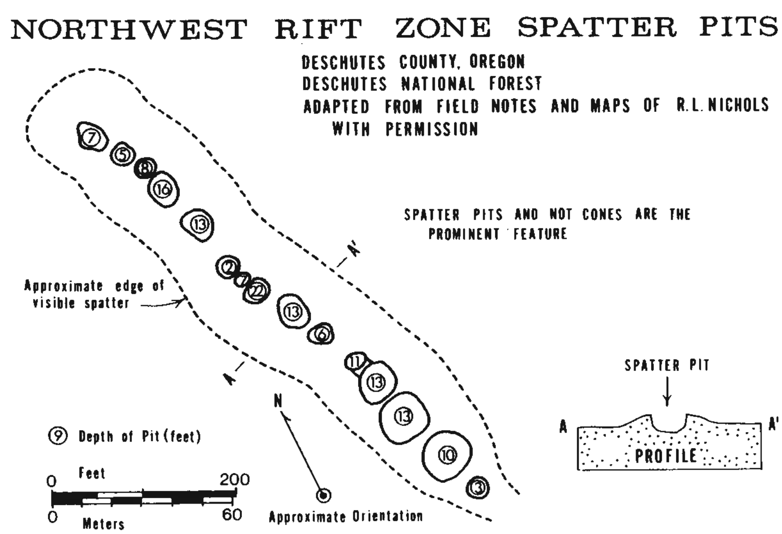


Figure 4. An alignment of spatter pits and low splatter ramparts along the upper segment of the Northwest Rift Zone of the Newberry Volcano. The exact orientation and location of this group are not known but aerial photograph interpretation suggests that it is found between the East Lake Fissure and the North Summit Flow. No open vertical conduits are found along this chain, though it is typical of others in which conduits are found.

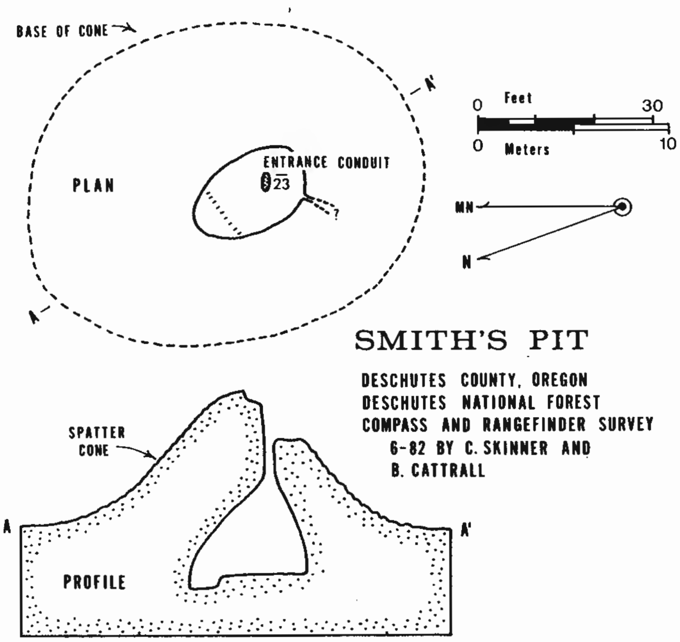


Figure 5. *Smith's Pit, Northwest Rift Zone, Newberry Volcano.*

(Williams, 1944:57; Peterson and Groh, 1965:29; Taylor, 1965:132 and 1967:20). It was described in some detail by Skinner (1979).

The OVC at this site is about 20 feet (6 m) in diameter and drops 24 feet (7 m) from the upper to the lower level cave system. Directly above the conduit (which merges smoothly with the upper level lava tube) is an open-topped spatter cone. In cross-section, the conduit is slightly oval-shaped with a remelted lining covered with short "lavacicle" stalactites.

7.2 SAND MOUNTAIN CHIMNEYS

Southwest of Sand Mountain, an east-west trending ridge of spatter rises above the surrounding forest. On top of this ridge are two OVCs: Century and Moss Pits (Figure 8).

Just west of the spatter ridge (which is the result of lava-fountaining along a fissure vent) is a crater 30 feet (9 m) in diameter, a former vent. The remnant of an OVC, identical in structure to the two intact ones, can be seen in the crater wall.

An entire complex of vents, including those at the Sand Mountain Chimneys, is located in a broad ridge at this site. It was the source of the Clear Lake lava flows. These are aa flows that moved west to form the east shore of Clear Lake.

Moss Pit is eight feet (2.5 m) in diameter at the entrance. It is 63 feet (19 m) deep. A small chamber at the bottom slopes downward another ten feet (3 m), for a total depth of 73 feet (22 m) (Nieland, 1970:233).

One-hundred fifty feet (46 m) east of Moss Pit and on the eastern edge of the spatter ridge is Century Pit. The entrance is three feet (1 m) in diameter. It is surrounded by a one to two-foot wall of spatter; the OVC drops vertically for 94 feet (29 m). In profile, the lower half of the OVC opens to a room measuring 10 by 25 feet (3 by 8 m) at the base of the shaft. At the western end of the bottom of the pit, an opening leads down an additional six feet before becoming blocked by breakdown (Nieland, 1970:235). These two OVCs were first mentioned by Taylor (1965:126; 1967:12) and were later mapped and described by Nieland (1970).

The entrances of both OVCs are typical: vertical circular pipes with relatively smooth remelted linings. I was not able to examine the lower sections of these two conduits. The elongate lower chambers that are shown in a revised version of Nieland's map (Figure 8) seem to be aligned along the axis of the eruptive fissure, suggesting that the structure of the lower segments of the shafts are controlled by the fissure or that the OVCs join an intact section of spatter-roofed open fissure vent.

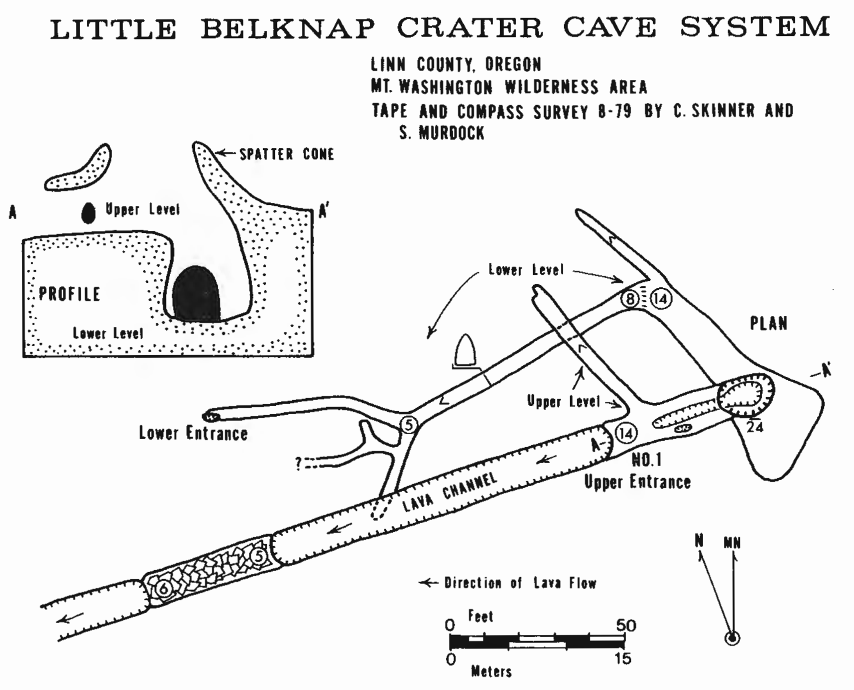


Figure 6. *The Little Belknap Crater Cave System, McKenzie Pass area, High Cascades.*

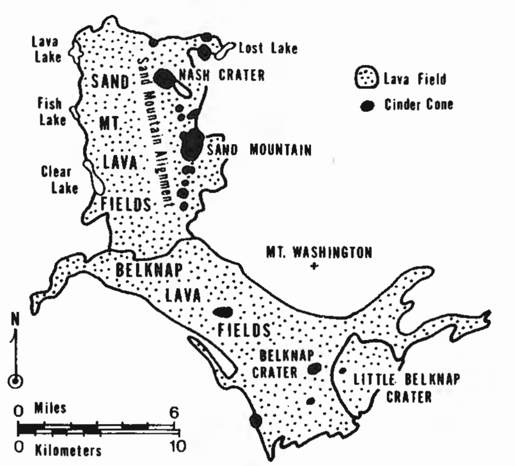


Figure 7. *Holocene lava fields found associated with Little Belknap Crater and the Sand Mountain Alignment, High Cascades (base map adapted from Taylor, 1965:123).*

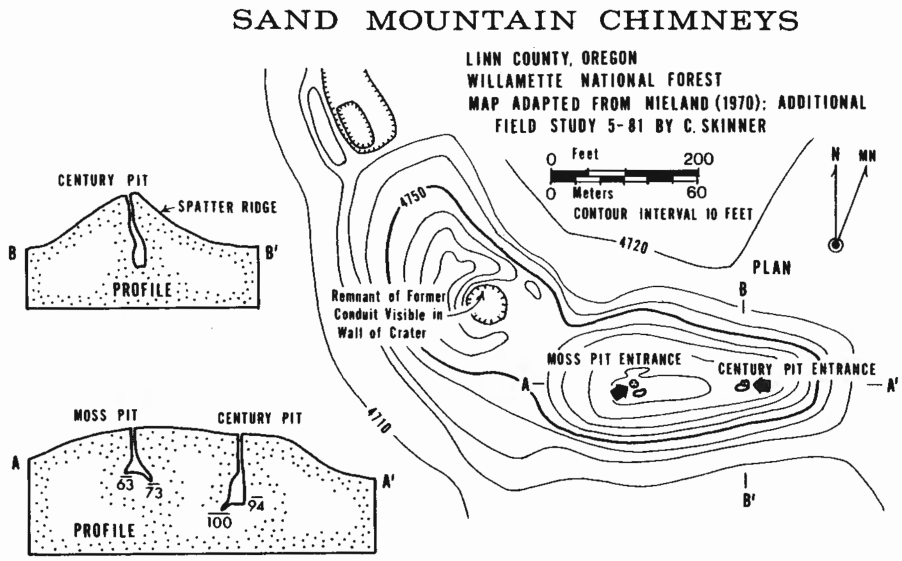


Figure 8. The Sand Mountain Chimneys (Century and Moss Pits), Sand Mountain Alignment High Cascades.

Alignment. As the eruption proceeded, the fissure widened, presumably through a process such as dike injection (Jackson and Swanson, 1970). A roof of accreted spatter up to 30 feet (9 m) thick was eventually built over part of open fissure (this process is discussed by Swanson, *et al.*, 1979:17,35,37). Two open conduit vents penetrate the spatter roof (conduits 1 and 2 in Figure 9). In the last stages of the eruption, magma was drained from the roofed fissure, possibly by the lava channel found at the base of the large spatter cone. This left a large, spatter-encrusted chamber aligned with the fissure vent. Two OVCs are three feet (1 m) in diameter and three more entrances into the fissure were left as the result of post-eruptive ceiling collapse or incomplete fissure roofing. The fissure cave can be penetrated to a depth of 150 and 160 feet (45 to 50 m).

A large spatter cone was built down slope from the roofed fissure segment. An OVC 25 feet (8 m) in diameter--the largest of any investigated in this study--is accessible through a low spot in the cone wall. This OVC drops about 40 feet (12 m), narrows, then curves toward the prominent lava channel at the lower margin of the spatter cone. Finally, it is blocked by breakdown. This OVC, incidentally, is the *only* conduit described in the paper (with the obvious exception of the three-foot Newberry example) that is accessible without specialized vertical descending and ascending equipment.

7.3 UPPER McKENZIE PITS

One of the most interesting of the OVC settings is an alignment of spatter cones, ramparts, OVCs and a roofed fissure vent (Figure 9). This vent complex, known as the Upper McKenzie Pits, houses the deepest volcanic pits reported in Oregon. Basaltic andesites from this fissure vent flowed west where they make up the eastern shore of Fish Lake.

The OVCs and roofed fissure cave at this site were the result of a fissure eruption that broke out on the flanks of Nash Crater, one of several major cones along the Sand Mountain

The structure of the OVCs at the Upper McKenzie Pits is typical though the development of the lava lining of the large spatter cone conduit is noticeably less developed than the lining of the smaller diameter OVCs.

These pits were first recognized in the literature by Taylor (1965:126; 1967:9), who considerably underestimated their depth. They were later mapped by Skinner 1980.

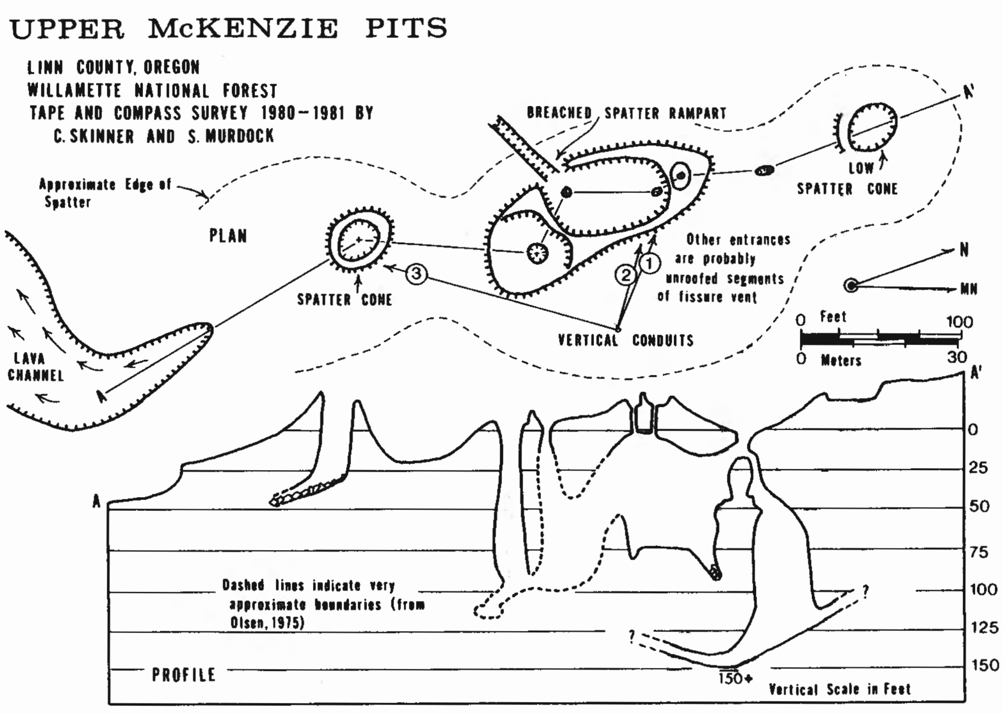


Figure 9. The Upper McKenzie Pits, Sand Mountain Alignment, High Cascades.

7.4 SANTIAM PIT

Near the northwest base of Nash Crater is another vent for two major flows that moved west to the shore of Fish Lake. The vent here is marked by a shallow cinder-and ash-filled depression ringed by a wall of spatter. Down slope from this vent is a small hornito that marks the entrance to Santiam Pit. In the center of this five-foot (1.5 m) high cone is a 30-foot (9 m) deep OVC three feet (1 m) in diameter. It joins a lava tube 50 feet (15 m) long, floored with sand. This lava tube is blocked by sand and debris at both ends.

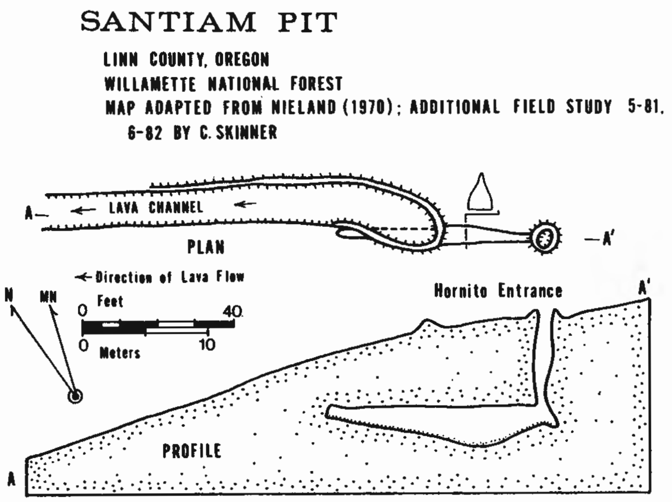


Figure 10. Santiam Pit, Sand Mountain Alignment, High Cascades.

Santiam Pit was first reported by Taylor (1965:126; 1967:9), though an early National Speleological Society list of Oregon caves is reported to have mentioned a Nash Crater Cave that may be Santiam Pit. The conduit was named and mapped by Nieland (1970:232-233).

This small hornito and conduit formed over a segment of lava tube that was fed by the nearby primary vent. This was the only OVC examined that was clearly associated with a rootless vent. The OVC displays the same circular form and remelted lining as those at primary vents. The presence of a lava tube in aa lavas is unusual, but not unknown (Warden, 1967; Wood, 1976b:22).

8.0 CLASSIFICATION AND SPELEOGENESIS

The open vertical vents examined in this study and those noted in the literature fall into two general categories: OVCs found at primary vents and OVCs found at rootless vents. These natural groupings provide the best criteria for the process-based classification of open conduits. Additionally, OVCs found at primary vents are generally associated with fissure eruptions, the conduit at Little Belknap Crater being a possible exception among those I examined. It is also possible that OVCs found at rootless vents could be fed by structures other than lava tubes, but no examples were noted either in Oregon or in the literature.

8.1 GENESIS OF OPEN VERTICAL CONDUITS AND ASSOCIATED LANDFORMS AT PRIMARY VENTS

Eruptive activity at primary fissure vents has been described by a number of authors. The hypothetical sequence of events pictured in Figure 11 is based on my interpretation of the observations of MacDonald (1959) and Swanson et al. (1979) of activity along the East Rift Zone of Kilauea and on summaries by Williams and McBirney (1979:71-73, 271).

Once activity has begun along an eruptive fissure vent, the tendency is, as the eruption continues, for fountaining or discharge of lavas to localize or focus along the vent. If, at the end of the eruptive activity, the magma level subsides or is diverted by the opening of another vent, the eruptive conduit may be left open. If it is well-developed, this will result in an OVC. This was seemingly the occurrence along the upper Northwest Rift Zone; activity there created numerous spatter pits, each a minor focus along the fissure vent. Depending on the length and volume of the eruption, spatter ejected from a vent builds various sizes of spatter cones or ramparts.

If the fissure vent is positively dilated, it may develop a roof of spatter through the accretion of crust and spatter to its upper walls. Spatter cones may develop, fed by conduits penetrating the roof, and holes may form through collapse, thus providing a vent for small lava flows and spatter (Swanson et al., 1979:37-38). Should the magma in the roofed section be withdrawn, an open chamber may remain. All of these events appear to be well documented at the Upper McKenzie Pits (Figure 9).

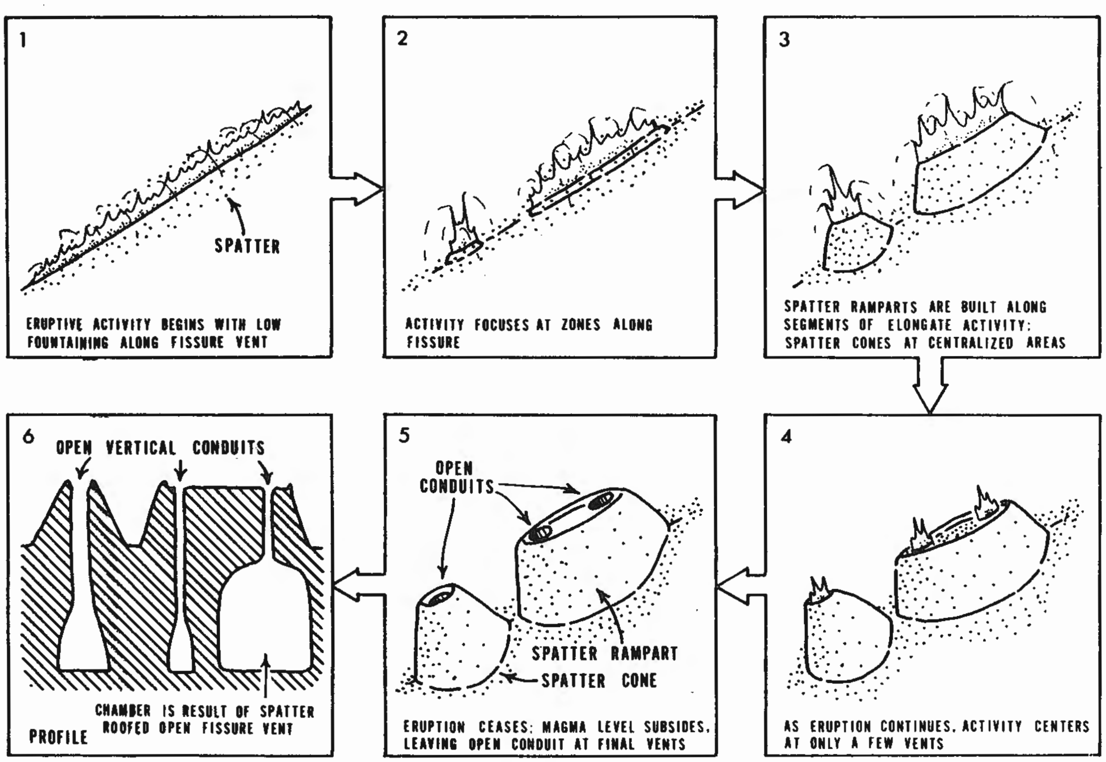


Figure 11. An eruptive sequence showing the formation of open vertical conduits and associated surface landforms at a primary vent.

8.2 GENESIS OF OPEN VERTICAL CONDUITS AND ASSOCIATED LANDFORMS AT SECONDARY VENTS

The processes that create hornitos and open conduits at rootless vents are considerably different than those operating at primary vents.

As lava flows are extruded from a vent, distinct lava channels soon form, channeling lava to the front of the flow. As the eruption progresses, the channel tends to become covered by jammed pieces of crust or by the merging of levees developed on the channel margins (Wentworth and MacDonald, 1953:43).

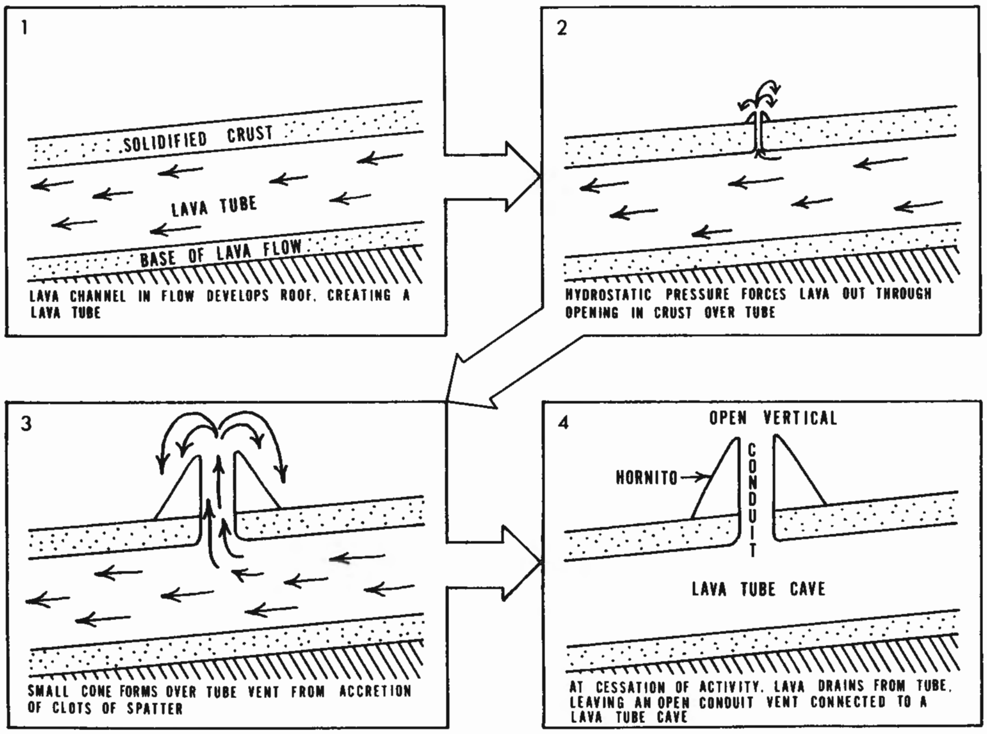


Figure 12. *An eruptive sequence showing the formation of an open vertical conduit, hornito and lava tube at a rootless vent (box 3 is adapted from Fielder and Wilson, 1975:80).*

Small vents may break out over the lava tubes, and gas-charged clots of spatter are thrown out, resulting in the construction of a hornito (Wentworth and MacDonald 1953:52). Several hornitos may sometimes be found aligned linearly or sinuously over a former tube.

At the cessation of activity at the vent, if the conduit remains unfilled, an open vent or OVC will result. When the feeder lava tube drains and remains uncollapsed, the OVC will join with the tube. This sequence of events is illustrated in Figure 12. Santiam Pit (Figure 10) illustrates this process as does the small hornito and lava tube combination shown in Figure 2.

9.0 COMPARATIVE RESULTS

As a result of the comparative investigation of the OVCs found in the six locations that I have described, generalization is possible about the associated landforms and cave types and about the age and composition of the

VERTICAL CONDUIT	ASSOCIATED AGE	REFERENCE
Santiam Pit	~600 dendrochronologic years B.P. 3850 ± 215 radiocarbon years B.P. maximum*	Roach, 1952:172 Taylor, 1967:41 Chatters, 1968:494
Upper McKenzie Pits	~600 dendrochronologic years B.P. 3850 ± 215 radiocarbon years B.P. maximum*	Roach, 1952:172 Taylor, 1967:41 Chatters, 1968:494
Sand Mountain Chimneys	~3000 radiocarbon years B.P. maximum**	Benson, 1965 Taylor, 1967:41
Little Belknap Crater Conduit	2883 ± 175 radiocarbon years B.P.	Taylor, 1967:42 Chatters, 1968:494
Smith's Pit	~6000 radiocarbon years B.P.?***	Peterson and Groh, 1969:76
Northwest Rift Zone Conduit	~6000 radiocarbon years B.P.****	Peterson and Groh, 1969:76 MacLeod *et al.*, 1981:85,89

* The flows from the Nash Crater vents overlie a radiocarbon dated unit, establishing that as the maximum age of the overlying flows.

** Overlies a lava flow that dammed the Upper McKenzie Valley, creating Clear Lake; drowned trees from the Clear Lake damming have associated radiocarbon dates of 3200 ± 220 years B.P. and 2705 ± 200 years B.P., establishing the maximum age of the lavas from the Sand Mountain Chimney vents at about 3000 years B.P.

*** Eruptive activity at Smith's Pit may be related to nearby fissure activity at Lava Cast Forest, an event dated at about 6000 radiocarbon years B.P.

**** These pits lie along a segment of the Northwest Rift Zone that has not been radiocarbon dated, but is bracketed by two dated and presumably contemporaneous lava flows, the Lava Cascade Flow and North Summit Flow. Radiocarbon dates associated with these two events are, respectively, 5800 ± 100 years B.P. and 6,090 years B.P.

Figure 13. *The ages of lavas associated with the open vertical conduits examined in this paper.*

	1	2	3	4	5	6	7	8	9	10
SiO_2	54.70	54.80	52.80	54.40	54.50	51.70	53.50	52.62	50.88	50.80
TiO_2	1.26	1.21	1.28	1.32	1.32	1.50	1.18	1.27	1.21	1.20
Al_2O_3	16.60	16.60	18.00	16.90	18.20	16.20	19.30	17.27	17.82	17.89
MgO	4.84	5.02	5.21	6.20	5.20	8.10	5.30	6.82	6.86	7.31
FeO	8.02	7.78	7.86	8.60	8.30	9.40	8.20	--	--	--
Fe_2O_3	--	--	--	--	--	--	--	9.32	9.32	9.17
MnO	0.16	0.16	0.15	--	--	--	--	0.14	0.14	0.14
CaO	8.43	8.37	9.18	8.80	8.40	9.10	8.60	8.28	8.28	9.40
Na_2O	3.80	3.84	3.79	--	--	--	--	3.59	3.59	3.19
K_2O	1.12	1.13	0.85	0.86	0.69	0.80	0.85	0.77	0.77	0.64
P_2O_4	0.26	0.25	0.23	--	--	--	--	0.25	0.25	0.30

Vertical Conduits

1. North Summit Flow, Northwest Rift Zone, Newberry Volcano (Beyer, 1973:15; sample NS-1).
2. Lava Cascade Flow, Northwest Rift Zone, Newberry Volcano (Beyer, 1973:15; sample LC-1).
3. Little Belknap Flow, Central High Cascades (Beyer, 1973:19; sample 17).
4. Clear Lake Flow originating from vent at Sand Mountain Chimneys, Central High Cascades (Anttonen, 1972:82; sample 47).
5. Fish Lake Flow originating from Nash Crater vent, Central High Cascades (Anttonen, 1972: sample 49).

Lava Tubes

6. Sawyer's Cave Flow, Central High Cascades (Anttonen, 1972:82; sample 13).
7. Sixmile Butte Flow, Central High Cascades (collected at Skylight Cave; Anttonen, 1972:80; sample 37).
8. Sims Butte Flow, Central High Cascades (collected at Ectomorph Ice Cave; X-ray fluorescence analysis by the author).
9. Lava Top Butte Southeast Vent Flow, Newberry Volcano (collected at Tie Cave; X-ray fluorescence analysis by the author).
10. Lava Top Butte Northwest Vent Flow (collected at entrance to small tube that drained lava pond; X-ray fluorescence analysis by the author).

Figure 14. *The composition of lavas (weight percent oxides) associated with the open vertical conduits examined in this paper. The composition of nearby lava tubes is shown for comparison.*

vertical conduits. The results of this comparative study are significant for at least two reasons:

1. OVCs could function as a "signature" for a particular type of volcanic system. Predictions of age and composition, for instance, might be made on the basis of the presence of an OVC.
2. The existence of OVCs might be predicted by the presence of certain known volcanic environments. It seems, for example, that a Holocene fissure vent that was the source of basaltic andesite lavas would be a likely place to look for an OVC.

9.1 ASSOCIATED LANDFORMS

All of the OVCs examined, both in the literature and in the field, were found associated with predictable varieties of surface landforms. OVCs at primary vent areas were found with either spatter cones or ramparts, while OVCs at rootless vents were found with hornitos. While aa lavas predominated, pahoehoe lavas were also present.

9.2 ASSOCIATED CAVE TYPES

The association of certain cave types with OVCs was less predictable than with the surface landforms. In general, OVCs at primary vents were found in conjunction with either spatter cone chambers or with roofed fissure vents. OVCs at rootless vents were generally found with lava tubes, though little might remain intact. On only one occasion was a lava tube found with a primary vent OVC (at Little Belknap Crater) and it seems to have played a quite different role than the tubes found at rootless vents.

9.3 AGE

The ages of the lava flows associated with the conduits investigated here are well known and are shown in Table 1. The exception to this is the tenuous relationship of Smiths Pit with the well-dated activity at the Lava Cast Forest Flow. The presence of Mazama ash provides a convenient time datum in this area, but the porous nature of the spatter cone containing the conduit makes it unclear whether its origin was pre- or post-Mazama. The freshness of the lavas indicate that a very late Pleistocene to Holocene age can be appropriately assigned to the cone and OVC.

My initial conclusion is that OVCs are geologically very transient features, quickly filling through collapse and accumulation of debris, and that they are probably confined to lavas of a Holocene or late Pleistocene age.

9.4 CHEMICAL COMPOSITION

The composition of some of the lavas associated with the Oregon OVCs is also available and is reported in Table 2. Analyses 1 through 5 are from samples collected at flows that are linked with the OVCs. Analyses 6 through 10 are from samples that were gathered at lava tubes that were found in the same general area as the investigated vertical conduits.

As can be seen in Table 2, the OVCs are found primarily in basaltic andesite or lava of similar composition (53-58 weight percent SiO_2). The silica composition of the units with lava tubes, on the other hand, shows a tendency to fall into the basaltic range (48-53 weight percent SiO_2).

There is some overlap between the two groups and the error inherent in the interlaboratory comparisons could nullify any differences, but there does appear to be a trend for OVCs to be found in lavas that are slightly more siliceous than flows in which lava tubes develop. Perhaps the higher viscosity of the more SiO_2-rich lavas (as shown by the predominance of aa lavas at OVC sites) is a factor in the formation of open vertical vents.

10.0 CONCLUSIONS

Open vertical volcanic conduits are an unusual and little described type of cavernous lava structure found in areas of Holocene and late Pleistocene basalts and basaltic andesites throughout the world. They are vertical pipes, coated with a remelted lava lining, that have remained unfilled by the final eruptive activity at a vent.

These open conduits appear in aa and pahoehoe lavas. They may occur singly or in alignments along fissure vents and as an adjunct structure to some other forms of lava caves. Open vertical conduits are present at both primary and secondary (rootless) vents and are invariably found in conjunction, respectively, with spatter cones and ramparts or hornitos. When found in association with a rootless vent, they may be connected to the still intact lava tube for which they originally acted as a vent. Conduits found at primary vents are often found associated with other cave types, including spatter cone chambers, spatter-roofed open fissure vents and, occasionally, with a lava tube that drained the magma from the conduit, leaving it open.

The surface diameter of most open vertical conduits is less than 25 feet (8 m) and more commonly is between ten and three (3 and 1 m). The depth of reported and observed open vertical conduits or of associated caves for which the conduits are a major component varies from a few feet to at least 165 feet (50 m).

It is likely that other OVCs exist in many other areas of extensive volcanic activity in the world. The presence of several conduits in Oregon suggest that open vertical conduits are an obscure, rather than rare volcanic feature.

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SPELEOLIFEROUS LAVA FLOWS ASSOCIATED WITH THE BROTHERS AND SUBSIDIARY FAULT ZONES OF CENTRAL AND SOUTHEASTERN OREGON

Ellen M. Benedict, Pacific University

ABSTRACT

The Pacific Northwest at the western edge of the North American Plate is impacted by the interactions of three types of plate boundaries. As the Pacific Plate slips northward toward subduction in the Gulf of Alaska, it is dragging western Oregon northward. During the last 10 to 12 million years, the terrain south of the Brothers Fault Zone has been extended an estimated 50 miles over a distance of 200 miles. The Brothers Fault Zone, along which magma has upwelled repeatedly, is the "pivot" between the older highly folded rocks of the Blue Mountain Province and the younger highly faulted rocks of the Basin and Ranger Province. The basaltic lava fields along the Brothers and subsidiary parallel fault zones include: the Horse, Arnold, Potholes, Matz, Lava Pass, Devils Garden, Squaw Ridge, Green Mountain, Four Craters, Diamond Craters, Voltage, Saddle Butte, Jordan Craters and Cow Lakes. Caves have been discovered in most of these lava fields; their basalts vary in age. A second group of cave flows are associated with the stratovolcanoes which result from magma produced by the subduction of the Juan de Fuca Plate. The highly plastic, small and thin, warm and youthful Juan de Fuca Plate, originating from a spreading center located about 270 miles offshore from the Oregon-Washington line, is subducting at an oblique angle under the more buoyant North American Plate. Examples of the stratovolcanoes with speleoliferous basaltic flows are Mt. St. Helens and Mt. Adams in southern Washington, Newberry Volcano in central Oregon, and Medicine Lake Volcano in northern California.

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